A Stereo Vision Measurement System Based on OpenCV

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Abstract—**A complete realization method of stereo vision measurement system based on Open Source Computer Vision(OpenCV) was presented in this paper. Firstly, camera calibration based on 3D grid target was used to establish the relationship between the positions of the pixels and the scene points. This step was accomplished by OpenCV functions. Secondly, Harris corner detection was selected to get the feature points. Then, corresponding points between stereo images were calculated by sparse point matching algorithm. And epipolar constraint was added in the matching process in order to improve the accuracy and efficiency. Finally, 3D world coordinates of each feature pixel were derived from matching relationship and camera model. And then, the real size of the object was ascertained subsequently. Experimental results showed that the proposed method can build a complete and viable stereo vision measurement system.**

Keywords-3D measurement; OpenCV; camera calibration; Harris corner detection; stereo matching

I. INTRODUCTION

One main purposes of stereo vision is to obtain the Three-dimensional (3D) information from the 2D images, and stereo vision is one of the hot spots in computer vision research for some applications such as unknown environment exploration [1] or Industrial measurement [2-3]. In the study, parallel binocular stereo vision measurement system [4-5] is generally applied. In order to acquire the 3D information, the basic principle of parallel binocular vision measurement is firstly to photograph the same scene by two parallel CCD cameras. Secondly, according to the camera mode, at least 6 feature points' world coordinates and image coordinates are needed to calibrate the cameras to establish the relationship between the position of the pixel and the scene point. Then, feature points are extracted from stereo images. And combined with the constraint condition, feature points matching between stereo images can be accomplished. Finally, the depth information of the object could be calculated by triangulation methods [6] according to matching relationship and camera parameters. On analysis of the geometric relationships, every key point's world coordinate can be obtained and the true size of the measured object can be precisely measured.

Open Source Computer Vision (OpenCV) is a library of programming functions for real time computer vision. It is free for both academic and commercial use. It has C++, C, Python and soon Java interfaces running on Windows, Linux, Android and Mac. The library has more than 2500 optimized common algorithms in image processing, machine vision, etc.

In this paper, camera calibration design and the feature points matching was achieved by functions given by OpenCV [7] under the environment of VC.

II. WORKING PRINCIPLE

The basic principle of Parallel binocular vision measurement is firstly to photograph the same scene by two parallel CCD cameras. Secondly, feature points are extracted from stereo images. And, combined with the constraint conditions for the corresponding points, feature points matching between stereo images can be accomplished. Then, using these corresponding points and camera parameters, the depth information of the object could be easily acquired on analysis of the geometric relationships among the various parts of the vision system. So every key point's world coordinate is obtained. Finally, the true size of the measured object can be precisely measured.

The schematic diagram of the binocular stereo camera system is shown in Fig. 1. Wherein, B is the distance of two cameras' optical centers. The optical axes of the two cameras are parallel. f is the focal length. (x_1, y_1), (x_2, y_2) are positions of space point W on the left image and the right image respectively. And $x=|x_1|-|x_2|$ is the parallax of the two 2D points.

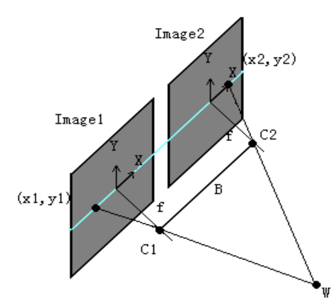

Figure 1. The schematic diagram of the binocular stereo camera system.

A. Calibration of Binocular Stereo Camera System

Camera calibration refers to building the relationship of the space point and its pixel position on the image which captured by your cameras. In this process, we need at least 6 feature points' world coordinates and their image coordinates to derive the following parameters for the cameras. And they could be divided into internal parameters and external parameters.

Transformation Matrix:

$$A = \begin{pmatrix} \alpha_x & \gamma & u_0 \\ 0 & \alpha_y & v_0 \\ 0 & 0 & 1 \end{pmatrix} \tag{1}$$

External Parameters:

$$R = \begin{pmatrix} r_1 & r_2 & r_3 \\ r_4 & r_5 & r_6 \\ r_7 & r_8 & r_9 \end{pmatrix} \quad T = \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix} \tag{2}$$

Where α_x, α_y, u_0, v_0 and γ are internal parameters of the linear model. $\alpha_x = f / d_x$ ($\alpha_y = f / d_y$) is the effective focal length of $u(v)$ axis. f represents the camera focal length and $d_x(d_y)$ respectively represents the horizontal size or vertical size of a single pixel of the CCD camera. Point (u_0, v_0) is the optical center of the binocular stereo camera system. γ is the factor of inclination of u axis and v axis.

R and **T** are the external parameters of the cameras in binocular stereo vision measurement system**.** Wherein **R** is the rotation matrix and **T** is the translation vector. They represent the relative position between the camera coordinates and world.

B. Extraction of Image Features

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To determine the three-dimensional information based on parallax from dual viewpoints, the most critical step is to determine the correspondence between different images of a same object point. One method to solve the problem is to select the appropriate image features for matching. Harris is an operator based on signal point characteristics extraction. In addition, it can extract point characteristics quantitatively [8]. Here, Harris corners were selected as feature points for matching. Gaussian smoothing filter was used to reduce the influence of image noises in feature extraction.

The criteria for Harris corner determination was shown as following:

- For each point (x, y) on the image I, compute the first derivative with respect to variable x and y. Here, Tx and Ty are gradient template respectively in x direction and y direction.

$$I_x = T_x \otimes I \quad I_y = T_y \otimes I \tag{3}$$

$$T_x = \begin{pmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{pmatrix} \; T_y = \begin{pmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{pmatrix} \tag{4}$$

- Compute, I_xI_x, I_xI_y and I_yI_y by the first order derivative.

- Compute gaussian convolution, where w is the Gauss template.

$$A = w \otimes I_x^2,\ B = w \otimes I_Y^2,\ C = w \otimes I_x I_y \tag{5}$$

- Compute Det and Tr of each pixel.

$$Det = AB - C^2 \tag{6}$$

$$Tr = A + B \tag{7}$$

- Compute the corner response R. And a point would be judged to be a Harris corner if R bigger than the threshold. Here, k is a constant.

$$R = Det - k \cdot Tr^2 \tag{8}$$

- Non-maximal inhibition is used to get the final result.

C. Feature Point Matching

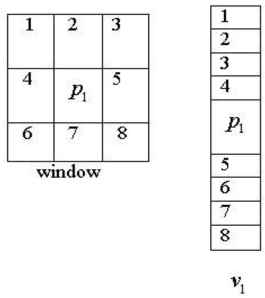


Figure 2. Convert a 3×3 window to vector

Feature point matching is the second phase of the binocular vision system and also the key area of the study. Its goal is to find matching points as much as possible. Researchers have made a lot of matching algorithm which could almost be divided into two parts, sparse point matching and intensive point matching. Sparse point matching which chiefly conducts the matching between the feature points, for instance, corners or contour points, can get a reliable match result efficiently. In this paper, sparse point matching has been adopted.

As shown in Fig. 2, the gray values of all the pixels in the 3 × 3 window of p_1 constitute the vector v_1. And v_2 can be obtained after the same process with p_2.

The discrimination principle in matching step was shown as following:

Firstly, equation (9) was used to calculate the angle between two vectors.

$$\cos\theta = \frac{v_1^T v_2}{\| v_1 \| \cdot \| v_2 \|} \tag{9}$$

Secondly, after the extraction of feature points, p_1 was selected as the match point in the left image. In order to improve the accuracy, the epipolar constraint was introduced in matching Step. So, the point which has the largest $cos\theta$ in the corresponding epipolar line would be regarded as the matching point.

In addition, during matching, the minimum of $cos\theta$ for matching was set to be 0.9 in order to remove some mismatching points.

D. Three-dimensional Reconstruction

On the basis of disparity estimation and camera calibration, three-dimensional reconstruction can be achieved [9-10]. Coordinate of a 3D point could be obtained with a pair of match points. Here, camera imaging model was applied to compute the 3D coordinates.

Assuming (u_1, v_1, 1) and (u_2, v_2, 1) are the image coordinates of the left and right images of space point P. Camera linear model can be expressed as equation (10).

$$\begin{pmatrix} u_2 \\ v_2 \\ 1 \end{pmatrix} = k_2 \cdot M \cdot \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \begin{pmatrix} u_1 \\ v_1 \\ 1 \end{pmatrix} = k_1 \cdot M \cdot \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{10}$$

Wherein, (X, Y, Z) is the world coordinate of same space point P. k_1, k_2 are scale factors. Matrix **M** has been obtained by camera calibration. Erasing k_1 and k_2, a ternary quadratic equation for X, Y and Z could be derived as equation (11). On this basis, 3D space point can be reconstructed.

$$\begin{aligned}
&(u_1m_{31}^1 - m_{11}^1)X + (u_1m_{32}^1 - m_{12}^1)Y + (u_1m_{33}^1 - m_{13}^1)Z = m_{14}^1 - u_1m_{34}^1 \\
&(v_1m_{31}^1 - m_{21}^1)X + (v_1m_{32}^1 - m_{22}^1)Y + (v_1m_{33}^1 - m_{23}^1)Z = m_{24}^1 - v_1m_{34}^1 \\
&(u_2m_{31}^2 - m_{11}^2)X + (u_2m_{32}^2 - m_{12}^2)Y + (u_2m_{33}^2 - m_{13}^2)Z = m_{14}^2 - u_2m_{34}^2 \\
&(v_2m_{31}^2 - m_{21}^2)X + (v_2m_{32}^2 - m_{22}^2)Y + (v_2m_{33}^2 - m_{23}^2)Z = m_{24}^2 - v_2m_{34}^2
\end{aligned} \tag{11}$$

III. STEREO VISION MEASUREMENT SYSTEM BASED ON OPENCV

In this paper, camera calibration design and the feature points matching were achieved by OpenCV functions under the environment of VC.

A. Camera Calibration

In the calibration process, the internal parameters and external parameters of cameras were determined by homography of the cross corners on the calibration block. Because the world coordinates of cross corners were already known, with the image coordinates obtained from extraction of the cross corners, the parameters of cameras can be derived.

The main steps:

- Use cvFindChessboardCorners to extract the corners of the calibration block.
- Use cvCalibrateCamera2 to get the parameters of cameras.

B. Feature Extraction and Matching

After obtaining images of the object from different perspectives, next steps are feature extraction and matching. The main procedures are as follows:

- Use cvFindFundamentalMat to calculate the basic matrix of the two images.
- Use cvComputeCorrespondEpilines to compute the corresponding epipolar in the other image of one point in the match image.
- Use cvMakeScanlines to calculate the coordinates of scan lines on both images.
- Use cvFindRuns to decompose each scan line.
- Use cvDynamicCorrespondMulti to accomplish the matching of each fragment.

IV. Experimental Result

Camera calibration, Harris corners extraction, sparse points matching and 3D reconstruction were implemented in the experiments. So, the true size of the measured object can be precisely measured.

Considering the practical application and task condition, calibration block was designed as shown in Fig. 3. It was a normal cube with 300mm side. Its three border surfaces were uniformly distributed with lattices of side length 75mm. There were 61 cross points on the block. World coordinates system was defined as shown in Fig. 3.

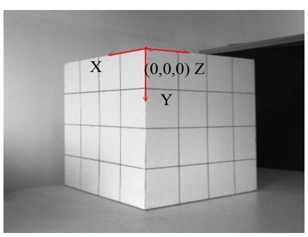
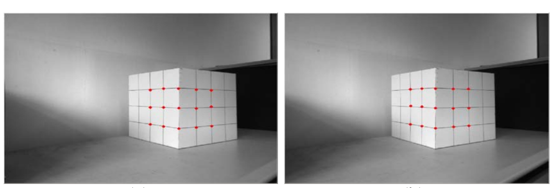


Figure 3. The calibration block

Here, the stereo vision measurement system was based on OpenCV. The corners detection result of calibration block was shown in Fig. 4. Using the world coordinates and image coordinates of the corners, the camera intrinsic parameters and external parameters were derived as shown in Table I.



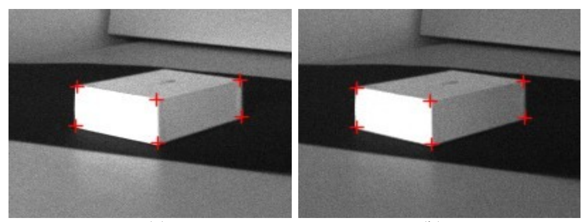
(a) (b)

Figure 4. The corners detection result:(a) left image, (b) right image

The Harris corners detection result of the measuring object was shown in Fig. 5. The feature points matching result and size of the object obtained from experiments were given in Table II. And the real size of the object was shown as Fig. 6.

TABLE I. THE LEFT CAMERA PARAMETERS.

The intrinsic parameters matrix A of camera
$A=\begin{pmatrix} 555.575 & 0.000 & 375.071 \\ 0.000 & 539.965 & 191.029 \\ 0.000 & 0.000 & 1.000 \end{pmatrix}$
The external parameters matrix of camera
$R=\begin{pmatrix} 0.622362 & -0.0722007 & -0.778879 \\ -0.00304159 & 0.994771 & -0.101474 \\ 0.782724 & 0.0722359 & 0.618911 \end{pmatrix}$ $T=\begin{pmatrix} 4.41766 \\ -4.72614 \\ 73.2753 \end{pmatrix}$



(a) (b)

Figure 5. Harris corners detection result:(a) left image, (b) right image

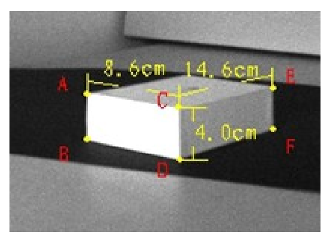


Figure 6. The real size of the object

It could be seen from Table II that the relative errors between the results of the 3D measurement based on the proposed method and the real size are quite small. Experimental results show that the proposed object size measurement method with stereo vision is simple and practical, and it can realize satisfactory results with good accuracy.

V. CONCLUSION

Stereo vision measurement system based on OpenCV was studied in this paper. It was a complete realization method of stereo vision measurement. Calibration based on 3D grid target was used to get the camera parameters. Harris corner detection was selected to get the feature points. Corresponding points were calculated by sparse point matching algorithm. And, 3D world coordinates of each feature pixel were derived from matching relationship and camera model. Experimental results showed that the proposed method can build a complete and viable stereo vision measurement system.

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TABLE II. FEATURE POINTS RECONSTRUCTION AND OBJECT SIZE MEASUREMENT RESULT

Tested points	**(u1, v1)**	**(u2, v2)**	**(X, Y, Z)**		**Real Length(cm)**	**Experimental result(cm)**	**Absolute error(cm)**	**Relative error (%)**
A	***(357,352)***	***(403,352)***	***(-2.1543, 25.5931, -2.9511)***	AC	8.6000	8.4657	0.2657	1.56
B	***(357,382)***	***(402,382)***	***(-2.1893, 29.4974, -2.9295)***					
C	***(409,362)***	***(459,362)***	***(-10.5725, 25.5176,-2.1161)***	CD	4.0000	4.0370	0.0370	0.92
D	***(410,395)***	***(460,395)***	***(-10.5891, 29.5536, -2.0278)***					
E	***(475,347)***	***(518,347)***	***(-7.5262, 25.6903, 12.3684)***	CE	14.6000	14.8024	0.2024	1.30
F	***(476,375)***	***(519,375)***	***(-7.6311, 29.2435, 12.3365)***					